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WATER RESOURCES INVESTIGATION
IN WEST PAKISTAN WITH THE
HELP OF ERTS IMAGERY -
SNOW SURVEYS

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(E77-10113) WATER RESOURCES INVESTIGATION
IN WEST PAKISTAN WITH THE HELP OF ERTS
IMAGERY: SNOW SURVEYS (Pakistan Water and
Power Development Authority) 43 p
HC A03/MF A01

N77-18526

Unclass

CSCL 08H G3/43 00113

SEPTEMBER, 1976

29810

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A B S T R A C T

Pakistan depends upon its agricultural produce to sustain its population. The pre-monsoon period March to June, is critical in respect of water supply in the rivers. This is also the period when the snow pack melts on the mountains and feeds the rivers. The two large reservoirs Mangla and Tarbela regulate the available water supply. If this water supply can be predicted for April to June, the reservoirs can be operated with confidence. High resolution LAND-SAT 2 Imagery of the snow-covered area in Upper Indus Basin has been obtained through NASA for the period January to June, 1975. From this imagery snow line maps have been prepared of selected basins with the help of Zoom Transfer-scope and Colour Additive Viewer. From these maps snow covered area has been planimetered with respect to time and hydrographs of the snow melt have been plotted for the period of melt from the data supplied by the stream-gauging network. Since only one season's imagery has been received; therefore the regression equation based on this could not be put to test. However, during the years this equation will be firmed up and used for forecasting snowmelt runoff. It is felt that snow line tracing and measurement with planimeter method can be successfully applied to the LAND-SAT Imagery of Upper Indus Basin.

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Lahore, Pakistan, in association with SUPARCO
and NASA.

I N T R O D U C T I O N

Pakistan is basically an agrarian country depending upon the agricultural produce to sustain its population. The pre-monsoon period March to June is critical in respect of the water supply in the rivers. The Rabi crops (Wheat, Oil-seeds, etc.) mature in April and Kharif crops (Sugarcane, Cotton, etc.) are sown during April - May. This is the time when almost no rainfall occurs and land depends entirely on the supply of water in the rivers for irrigation through the vast network of canals. The available water supply has to be rationed and used carefully to derive the optimum benefits from the irrigated land. The two large reservoirs that Pakistan has built at Mangla and Tarbela are generally at the lowest level in April having been continuously depleted during the winter. Yet further releases are to be made during the spring.

Rivers of the Indus Basin rise in the mountains with elevations as high as 8,500 meters. These mountains are covered with snow during winter (January to March). The snow starts melting towards the end of March and continues

through the summer. River flows consist mostly of the snow-melt during this period. If flows can be predicted with some accuracy, the reservoir operations can be planned with confidence and canal system can be run on rational basis. Such predictions cannot be made without snow surveys. The ground methods of snow surveys are expensive, time-consuming and difficult. Luckily with the advent of Land-satellites it has become possible to map the earth's surface at fixed intervals. Land-satellite 1 and Land-satellite 2 scan the earth every 18 days each. These satellites produce high resolution images of the earth's surface which when interpreted properly give the area of snow cover. The snow cover area can be related with the snow-melt run-off at strategic points. This can give a base for predicting the snow-melt run-off.

STUDY AREA AND DATA SOURCES

WAPDA has entered into an Agreement with NASA (National Aeronautics and Space Administration), through SUPARCO (Pakistan Space and Upper Atmosphere Research Committee) in May 1975 - "29810, Water Resources Investigation in West Pakistan with the help of ERTS Imagery - Snow Surveys". Under this agreement NASA had to supply Land-Sat 2 imagery of the project area beginning January 1975. The project area is bounded by the coordinates 33.00N to 37.00N and 71.00E to 78.00E (Figure - 1). So far NASA has supplied for the period January to June 1975 the following imagery:-

S.No	Scene ID No.	Date	CENTRE POINT		Band
			Lat. N	Long. E	
(1)	(2)	(3)	(4)	(5)	(6)
1.	2023-04554	14-2	34°-31'	75° - 20'	4,5
2.	2025-05071	16-2	34°-28'	72° - 25'	4,5,7
3.	2025-05064	16-2	35°-54'	72°-52'	4,5,7
4.	2025-05062	16-2	37°-20'	73°-19'	4,5
5.	2026-05125	17-2	34°-29'	70° - 59	4,5,7
6.	2026-05123	17-2	35°-55'	71°-25'	4,5,7
7.	2026-05120	17-2	37°-21'	71°-53'	4,5,7
8.	2040-04501	3-3	33°-13'	76°-19'	4,5,7
9.	2040-04495	3-3	34°-39'	76°-46'	4,5,7
10.	2043-05070	6-3	34°-34'	72°-26'	4,5,7
11.	2044-05122	7-3	35°-56'	71°-26'	4,5,7
12.	2044-05120	7-3	37°-22'	71°-54'	4,5,7

(1)	(2)	(3)	(4)	(5)	(6)
13.	2061-05065	24-3	34°-31'	72°-26'	4,5,7
14.	2061-05062	24-3	35°-57'	72°-54'	4,5,7
15.	2061-05060	24-3	37°-23'	73°-21'	4,5,7
16.	2062-05213	25-3	34°-31'	71°-01'	4,5,7
17.	2062-05121	25-3	35°-57'	71°-27'	4,5,7
18.	2062-05114	25-3	37°-22'	71°-55'	4,5,7
19.	2077-04552	9-4	34°-33'	75°-14'	4,5,7
20.	2078-05010	10-4	34°-32'	73°-54'	4,5,7
21.	2078-05004	10-4	35°-58'	74°-21'	4,5,7
22.	2079-05065	11-4	34°-29'	72°-26'	4,5,7
23.	2079-05062	11-4	35°-55'	72°-53'	4,5,7
24.	2079-05060	11-4	37°-21'	73°-21'	4,5,7
25.	2080-05123	12-4	34°-28'	70°-53'	4,5,7
26.	2095-04545	27-4	35°-52'	75°-70'	4,5,7
27.	2095-04543	27-4	37°-17'	76°-07'	4,5,7
28.	2096-05010	28-4	34°-26'	73°-48'	4,5,7
29.	2096-05004	28-4	35°-51'	74°-14'	4,5,7
30.	2096-05001	28-4	37°-17'	74°-42'	4,5,7
31.	2098-05114	30-4	37°-10'	71°-45'	4,5,7
32.	2116-05121	18-5	34°-23'	70°-57'	4,5,7
33.	2116-05115	18-5	35°-49'	71°-23'	4,5,7
34.	2130-04495	1-6	32°-59'	76°-09'	4,5,7
35.	2131-04552	2-6	34°-33'	75°-14'	4,5,7
36.	2131-04545	2-6	35°-47'	75°-35'	4,5,7

(1)	(2)	(3)	(4)	(5)	(6)
37.	2131-04543	2-6	37°-12'	76°-03'	4,5,7
38.	2132-05010	3-6	34°-18'	73°-42'	4,5,7
39.	2132-05001	3-6	37°-10'	74°-35'	4,5,7
40.	2133-05065	4-6	34°-19'	72°-15'	4,5,7
41.	2133-05062	4-6	35°-45'	72°-42'	4,5,7
42.	2148-04500	19-6	33°-03'	76°-08'	4,5,7
43.	2149-04550	20-6	35°-56'	75°-34'	4,5,7
44.	2149-04543	20-6	37°-22'	76°-07'	4,5,7
45.	2150-05002	21-6	37°-19'	74°-35'	4,5,7
46.	2151-05060	22-6	37°-21'	73°-10'	4,5,7
47.	2152-05124	23-6	34°-27'	70°-48'	4,5,7
48.	2152-05121	23-6	35°-53'	71°-15'	4,5,7
49.	2152-05115	23-6	37°-18'	71°-42'	4,5,7

Only this imagery has been analysed and used for this report. Imagery for the snow season 1976 is yet to be received from NASA.

M E T H O D S

The images were put through Colour Additive Viewer and the Zoom Transfer-scope and the workable images were separated. The Indus Basin was then divided into eight sub basins given below and shown in Figures 2 to 9:-

1. Swat River near Kalam	area	780 sq. mi.
2. Chitral River at Chitral		4,400 sq. mi.
3. Kunhar River at Naran		400 sq. mi.
4. Indus River at Besham		62,700 sq. mi.
5. Kishan Ganga River at Muzaffarabad		2,810 sq. mi.
6. Jhelum River at Kohala		9,610 sq. mi.
7. Hunza River at Dainyor Birdge		5,080 sq. mi.
8. Gilgit River at Gilgit		4,670 sq. mi.

With the help of Zoom Transfer-scope and Colour Additive Viewer, overlays of all the sub basins were prepared for each day of the available images. On these overlays snow covered area was marked in colour and was calculated with a planimeter. Eighteen days per square mile river flows were tabulated. The percent snow-covered area and eighteen days per square mile river flows were plotted on a time base. These plots have been shown in Figures 10 to 17.

C O N C L U S I O N

Figures 10 to 17 indicate that a relationship is possible between the snow covered area on a particular date and the resulting snow melt runoff during the subsequent period although snow depth and water equivalent have not been directly measured. The relationship is likely to take the form of a linear regression equation of the type $R = aS + b$. About 5 years data will be needed to confirm this conclusion.

The confidence level reflected by $r^2 = 0.976$ has not yet been put to test. This will be done when sufficient data become available over the years. However, it can be said with confidence that confidence level shall remain within tolerable limits. The equation for this particular analysis is

$$R = 1.11 + 1.02 A$$

Where R = April - August Snow Melt Run Off in MAF.

A = Area Under Snow on 1st of April in 1000 Sq. Miles.

R E S U L T S A N D D I S C U S S I O N

An examination of Figures 10 to 17 reveals that the snow cover increases as we travel from South to North. The snow starts melting earlier on the southern latitudes and stays longer on the northern latitudes. On the southern latitudes the snow starts melting towards the middle of February whereas in the northern latitudes the melting starts generally towards the end of March. Higher mountain peaks are encountered as we travel from South to North. In general, it can be assumed that the snow melt starts about the first of April. By the end of June about 50% of the basin becomes free of snow. The remaining 50% of the snow cover keeps melting through the summer. Towards the end of August a recession starts in the snow melt hydrographs till it hits the base flow towards the end of October.

A regression equation of the type $R = aS + b$ with R and S being the runoff in Million Acre-feet from April to August and area under snow in 1000 sq. miles on 1st of April respectively, has been attempted which shows encouraging results (Figure - 18). Since the regression is based on only one season's data it is expected to change. However, with four to five years of data a firm equation is expected to emerge.

A C K N O W L E D G E M E N T S

The author is grateful to NASA for providing financial support and to EROS Data Centre for sending the imagery. The author is also grateful for the help SUPARCO provided by way of handling the correspondence and by making their instruments available for interpretation. The author is grateful to Surface Water Hydrology Project for supplying the run-off data. The author is in particular grateful to Sh. Mohammad Hussain, Co-Investigator, who spent long hours on the interpretation of the images.

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REGRESSION ANALYSIS

S.No	Name of Station	Catchment area Sq. Mi.	On 1.1.71 snow area Sq. Mi.	RUN OFF IN 10 ⁶ ACRE-Feet							Direct Rain- fall	Snow Melt
				APR	MAY	JUN	JUL	AUG	Total			
1.	Swat River near Kalam	780	745	.091	.396	.565	.543	.485	2.08	.35	1.730	
2.	Kunhar River at Naran	400	384	.042	.215	.298	.230	.146	.931	-	.931	
3.	Chitral River at Chitral	4400	4206	.199	.408	1.050	1.630	1.740	5.027	-	5.027	
4.	Jhelum River at Kohala	9610	4901	1.093	1.820	1.771	1.858	1.593	8.135	1.25	6.885	
5.	Kishan Ganga River at Muzaffarabad	2810	2127	.403	.880	.948	.755	.523	3.509	-	3.509	
6.	Gilgit River at Alam Bridge	10100	9010	.204	.613	2.015	3.389	3.803	10.024	-	10.024	
7.	Hunza River at Dainyor Bridge	5080	4724	.110	.303	.976	2.046	2.734	6.169	-	6-169	

S.No.	X Area Under Snow 10 ³ Sq. mi on April 1	Y Runoff April - August 10 ⁶ Acre-feet	XY	X ²
1.	.745	1.730	1.29	0.555
2.	.384	0.931	0.3575	0.147
3.	4.206	5.027	21.143	17.690
4.	4.901	6.890	33.76	24.012
5.	2.127	3.509	7.464	4.524
6.	9.010	10.024	90.3162	81.18
7.	4.724	6.169	29.143	22.316
Total	26.097	34.280	182.00	150.43

$$\bar{X} = 3.722$$

$$\bar{Y} = 4.897$$

$$\overline{XY} = 18.227$$

$$\bar{X}^2 = 13.85$$

Sr. No.	$X_o - x_i - \bar{x}$	$Y_o - y_i - \bar{y}$	$X_o Y_o$	X_o^2	Y_o^2
1.	-2.977	-3.167	9.428	8.862	10.03
2.	-3.338	-3.966	13.238	11.142	15.73
3.	0.484	0.130	0.063	0.234	0.027
4.	1.179	1.993	2.35	1.390	3.972
5.	-1.595	-1.388	2.214	2.544	1.927
6.	5.288	5.127	27.036	27.963	26.286
7.	1.002	1.272	1.274	1.004	1.618
Total			55.603	53.139	59.584

REGRESSION EQUATION

$$y = a + bx$$

$$b = \frac{E x_i y_i - N \bar{x} \bar{y}}{E x_i^2 - N \bar{x}^2}$$

$$a = \bar{Y} - b \bar{x}$$

$$b = \frac{182 - 7 \times 18.227}{150.43 - 7 \times 13.85}$$

$$1.017$$

$$a = 4.897 - 1.017 \times 3.722$$

$$1.11$$

$$\text{or } Y = 1.11 + 1.02 X A$$

$$R = 1.11 + 1.02 A$$

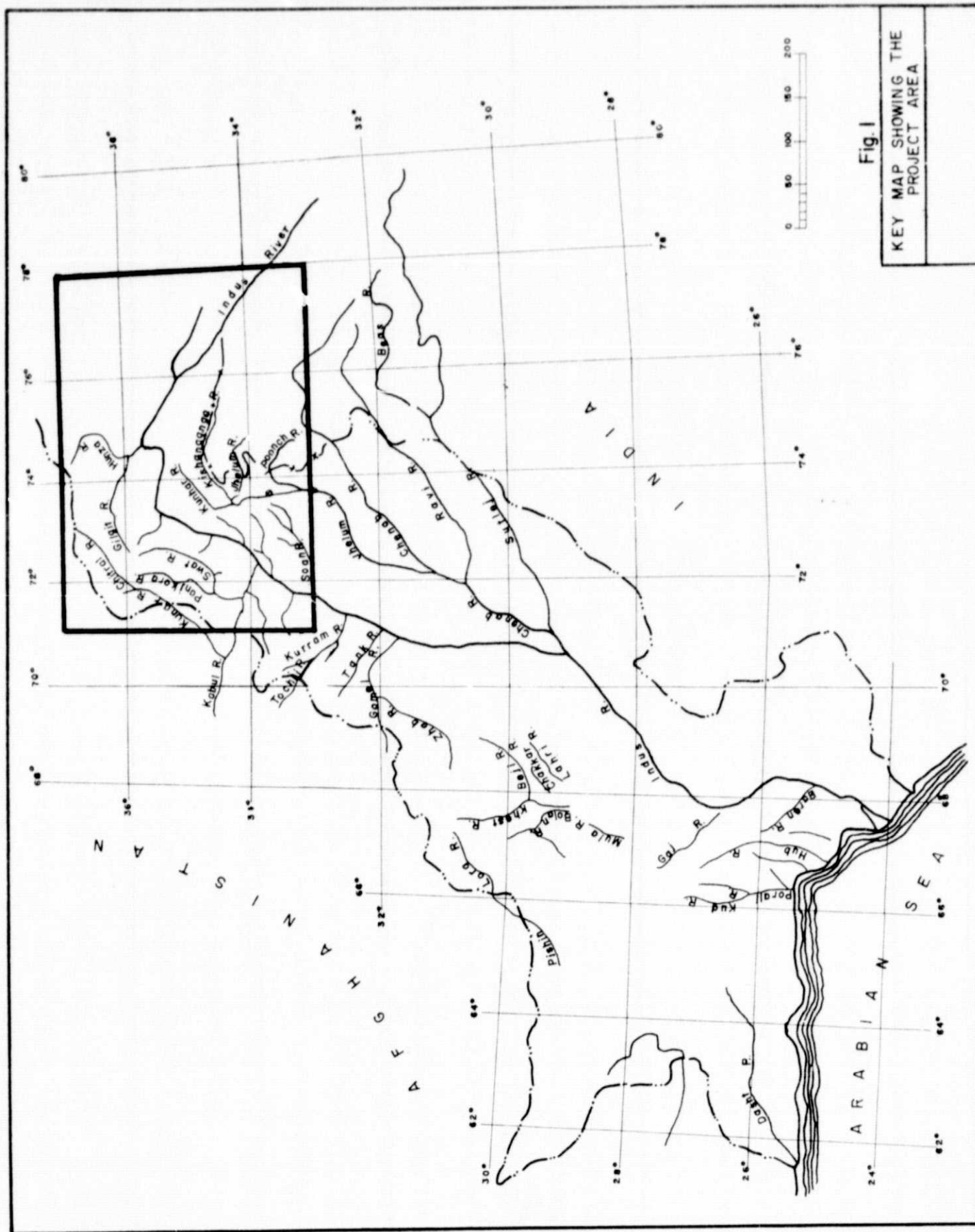
R - Snow melt runoff in 10^6 Acre-feet.
(April - August)

A - Area under Snow on first of April.

$$\frac{E x_o y_o}{(E x_o^2) \times E (y_o^2)} = \frac{55.603}{\sqrt{53.139 \times 59.584}}$$

$$0.988$$

$$0.976$$



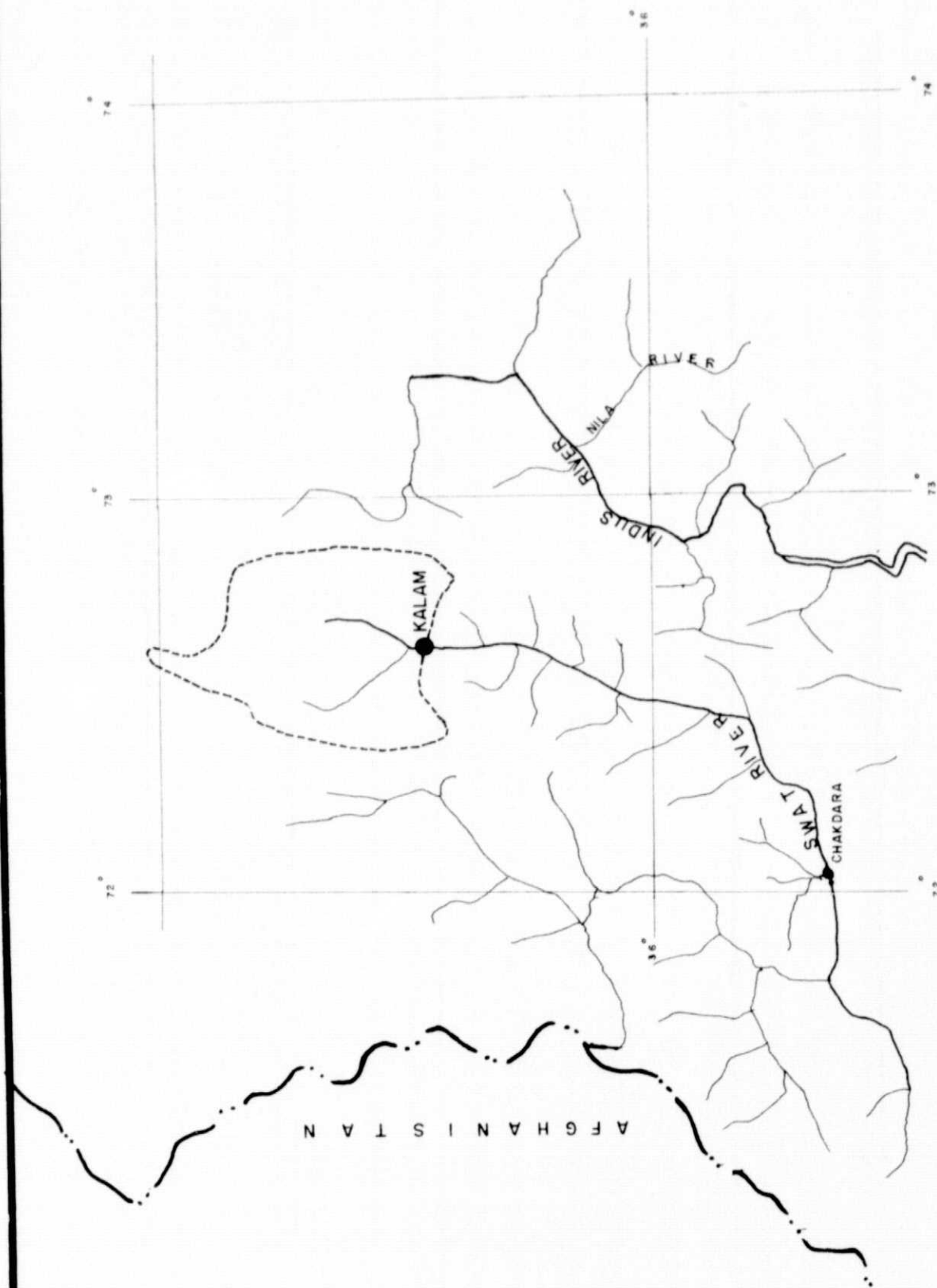


Fig. 2 SWAT RIVER NEAR KALAM
AREA = 780 Sq. Miles

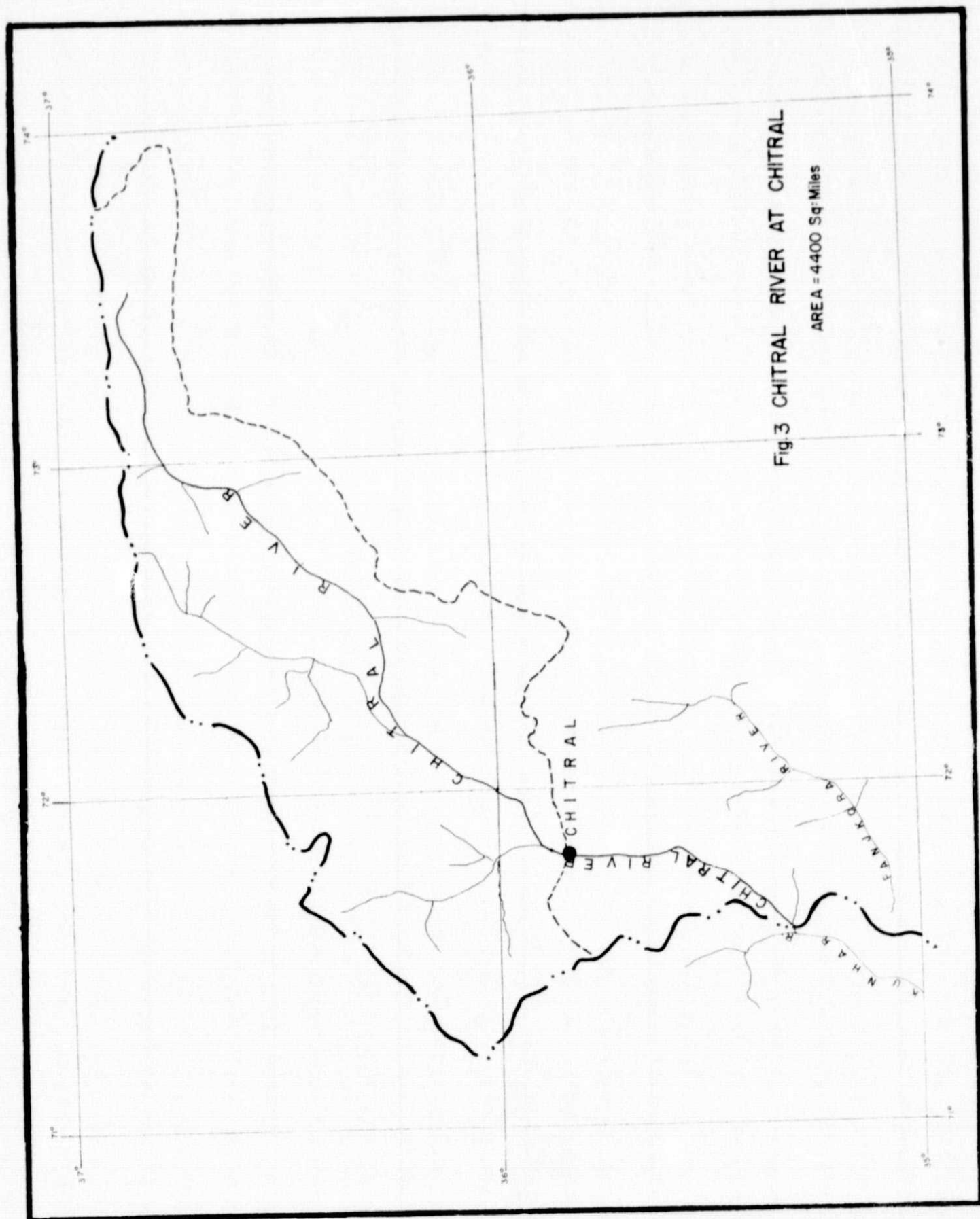


Fig. 3 CHITRAL RIVER AT CHITRAL

AREA = 4400 Sq. Miles

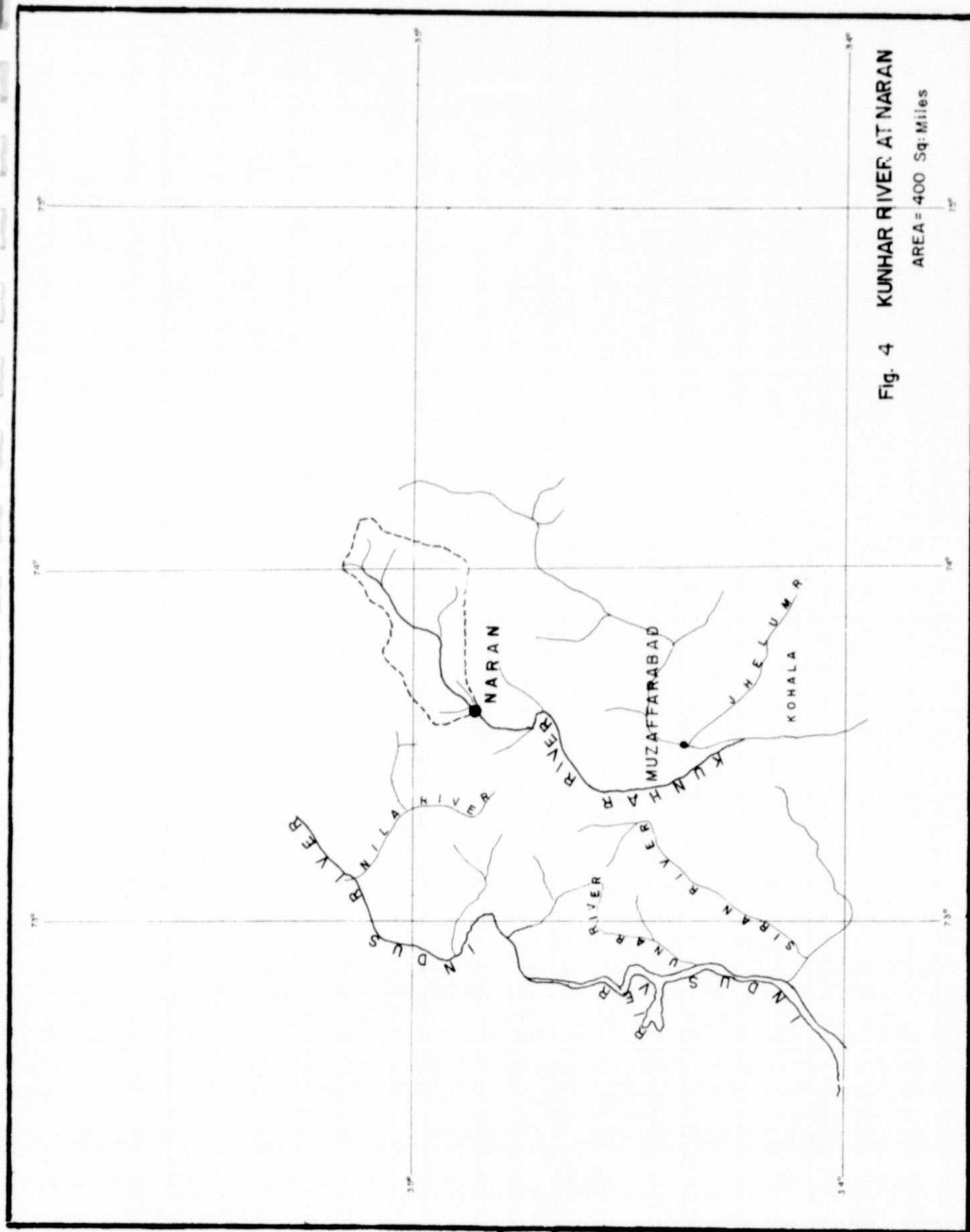


Fig. 4 KUNHAR RIVER AT NARAN

AREA = 400 Sq. Miles

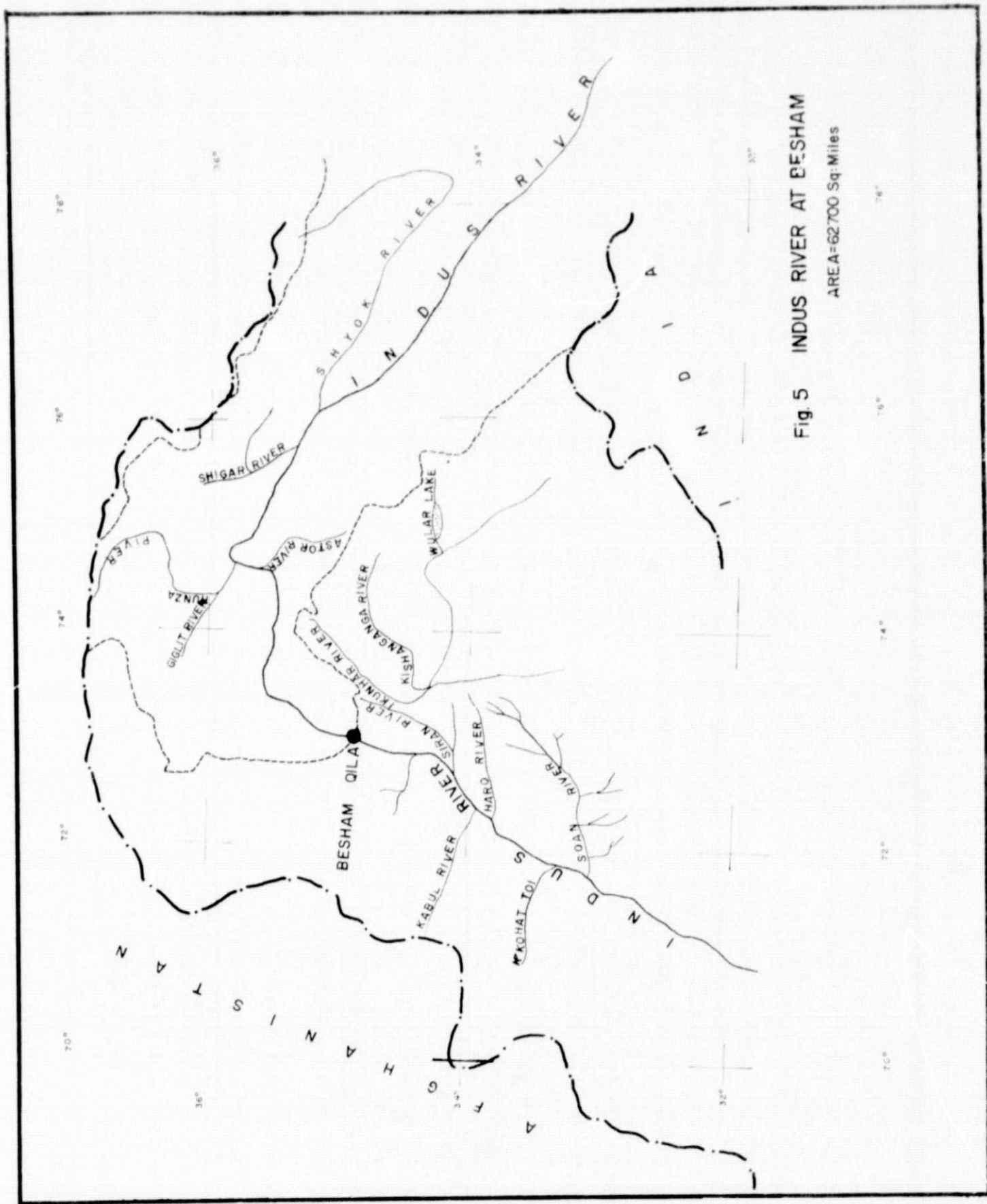


Fig. 5 INDUS RIVER AT BESHAM
AREA=62700 Sq. Miles

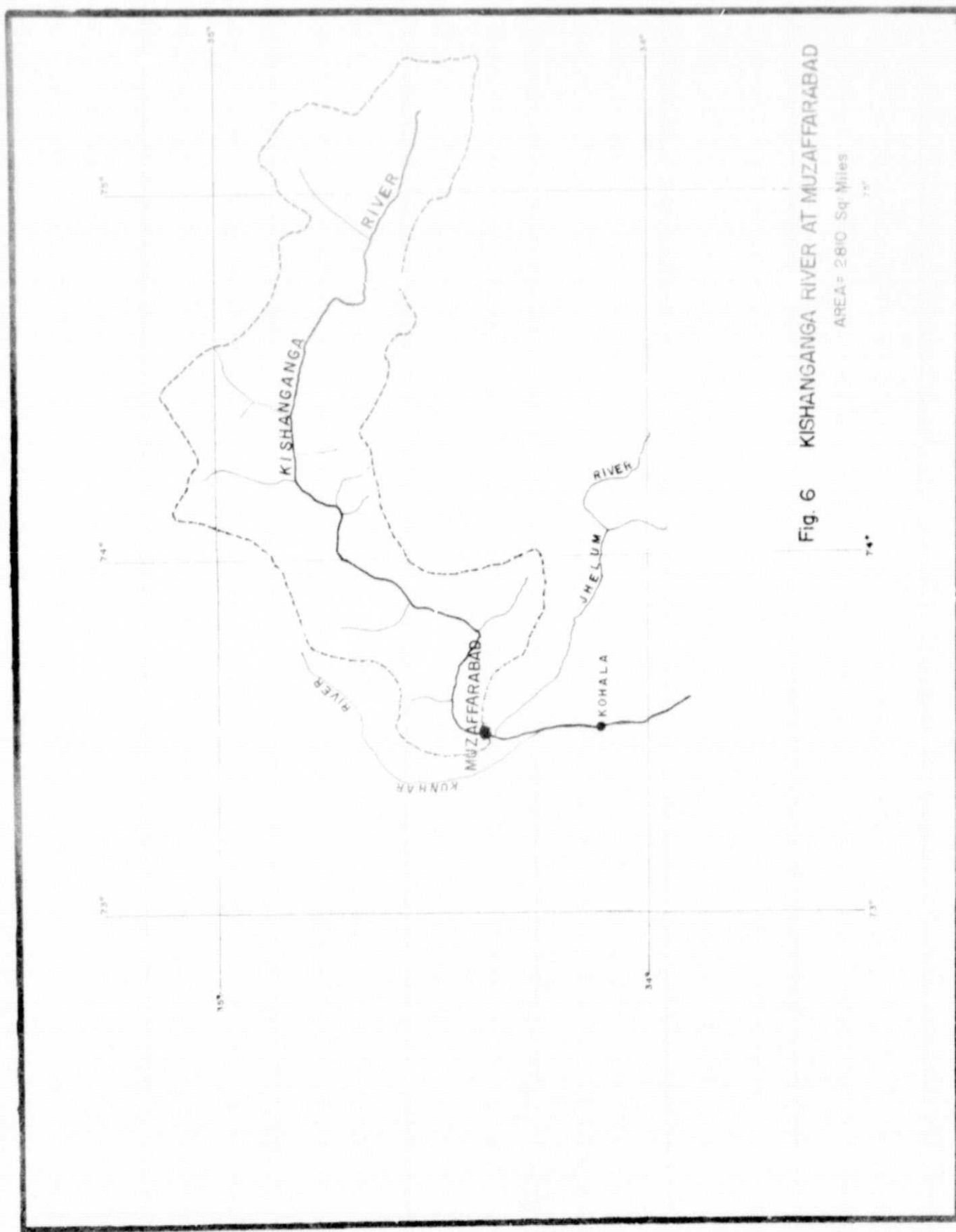
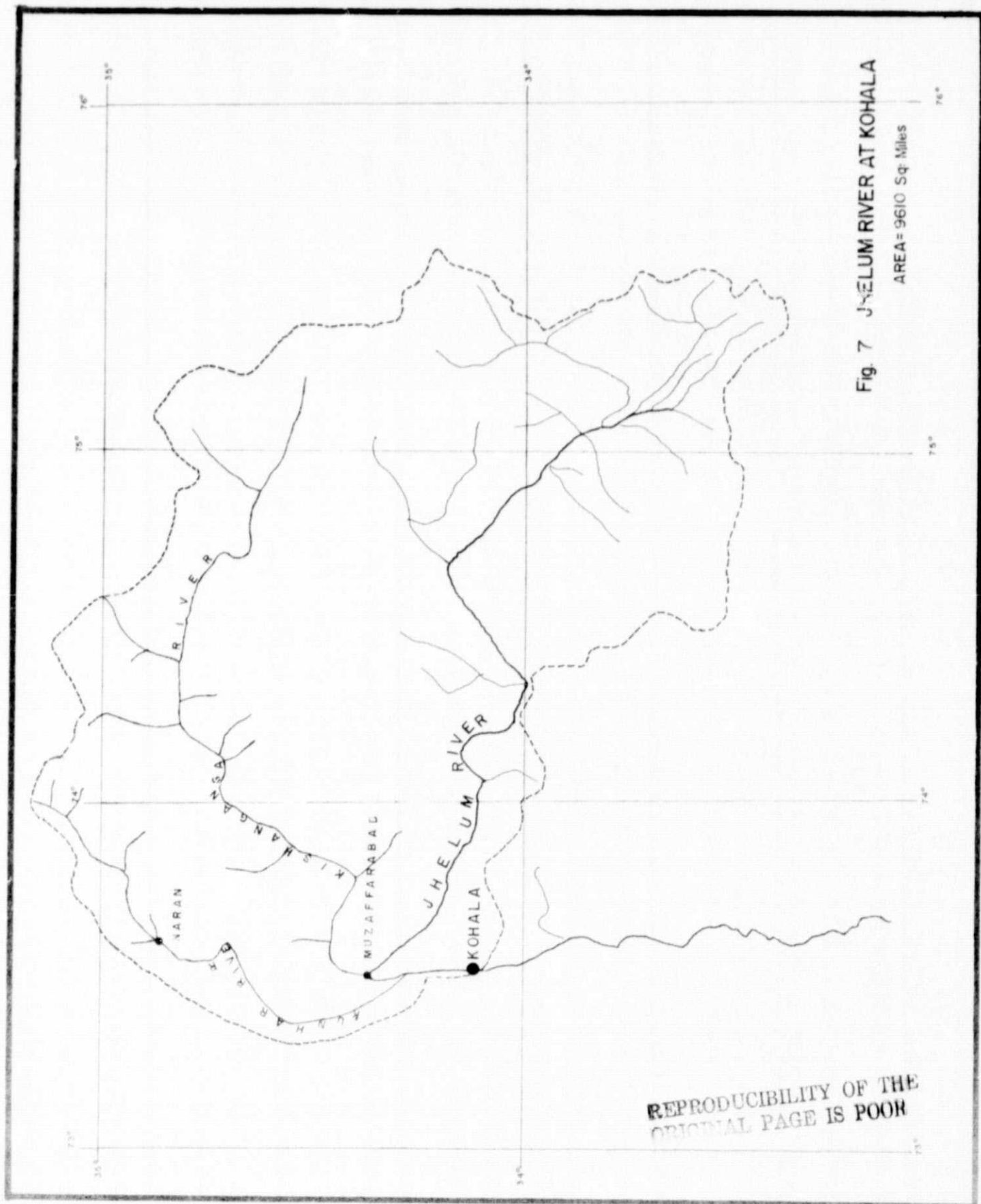


Fig. 6 KISHANGANGA RIVER AT MUZAFFARABAD



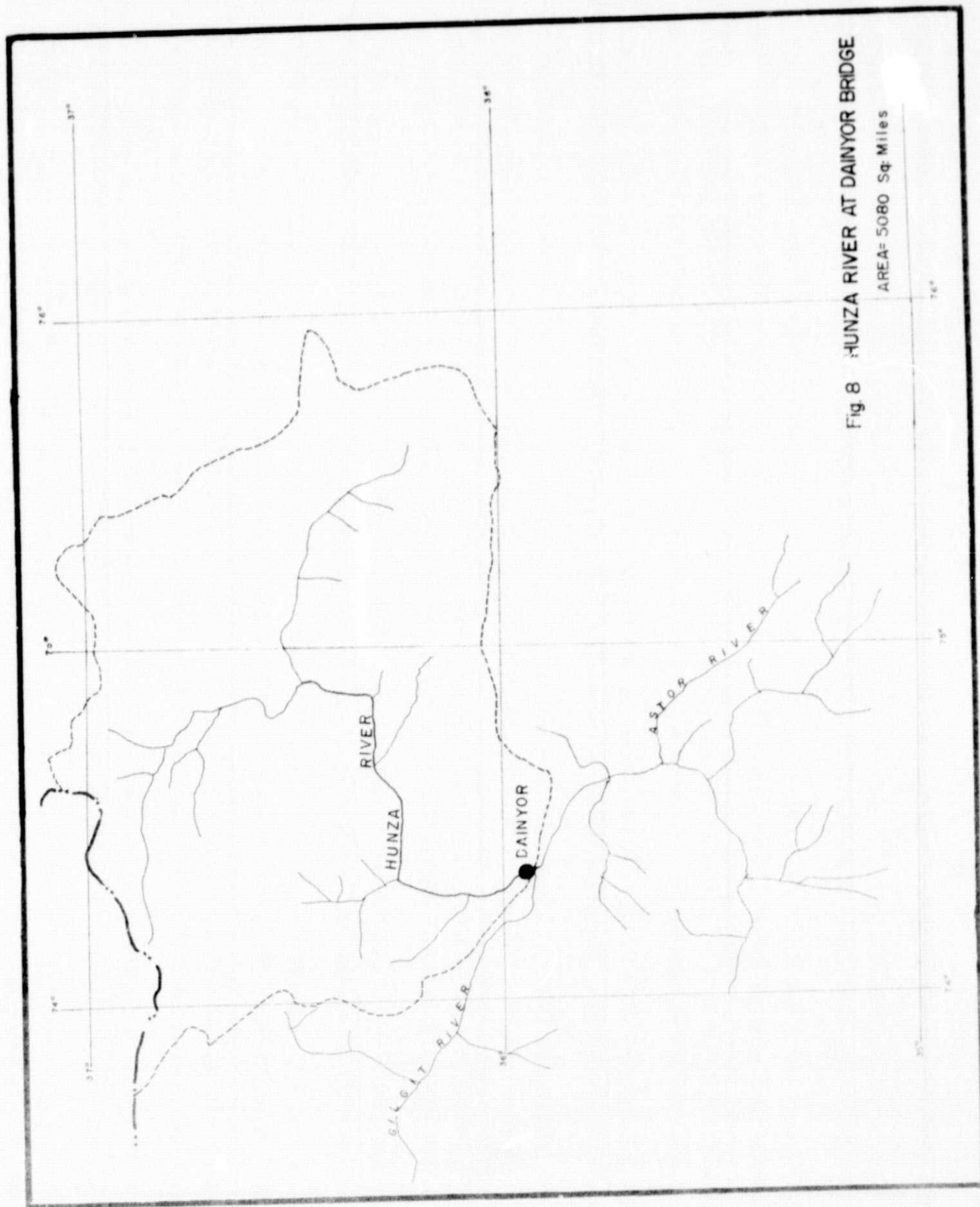


Fig. 8 HUNZA RIVER AT DAINYOR BRIDGE

AREA= 5080 Sq. Miles

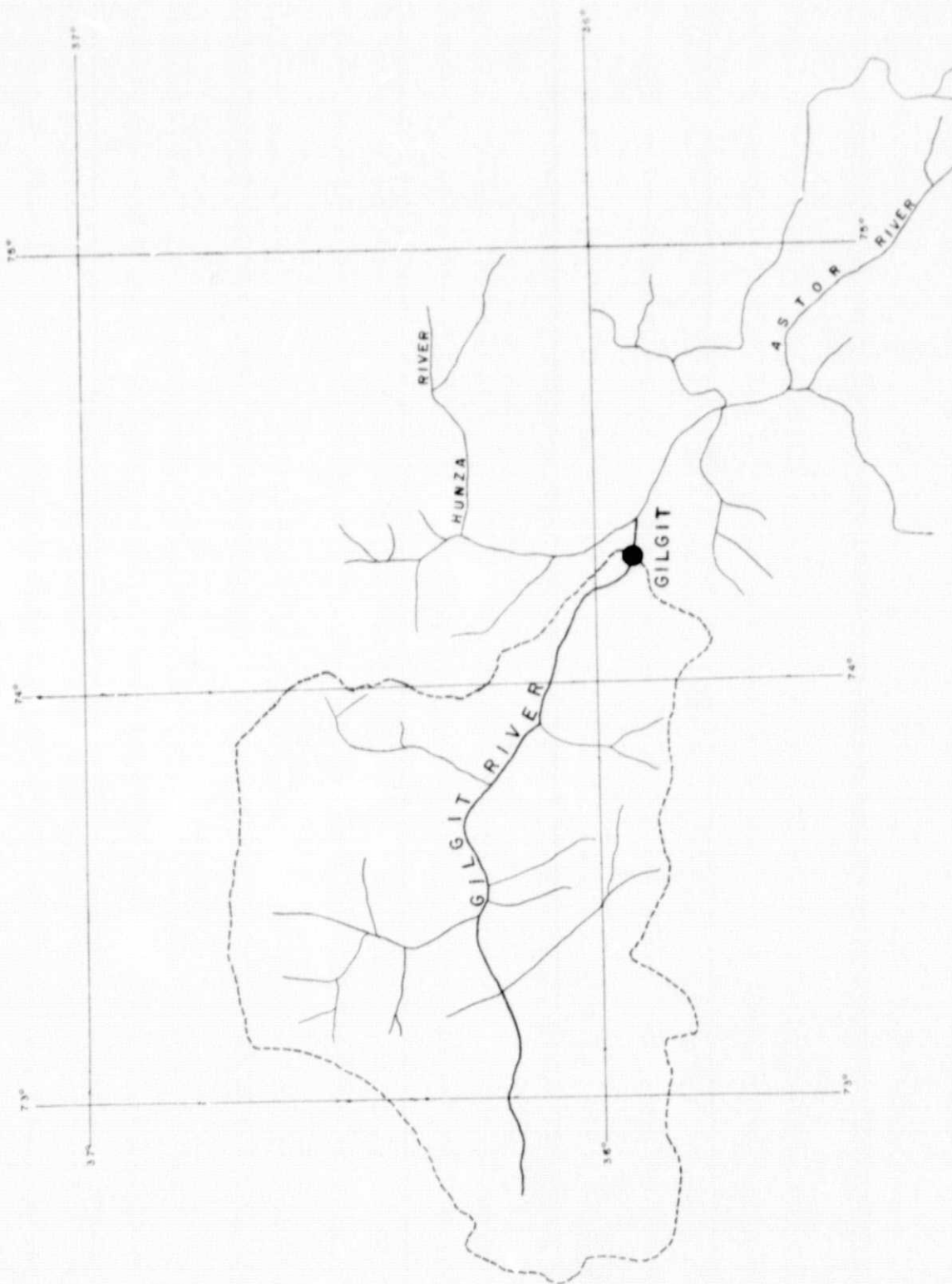


Fig 9 GILGIT RIVER AT GILGIT

AREA=4670 Sq Miles

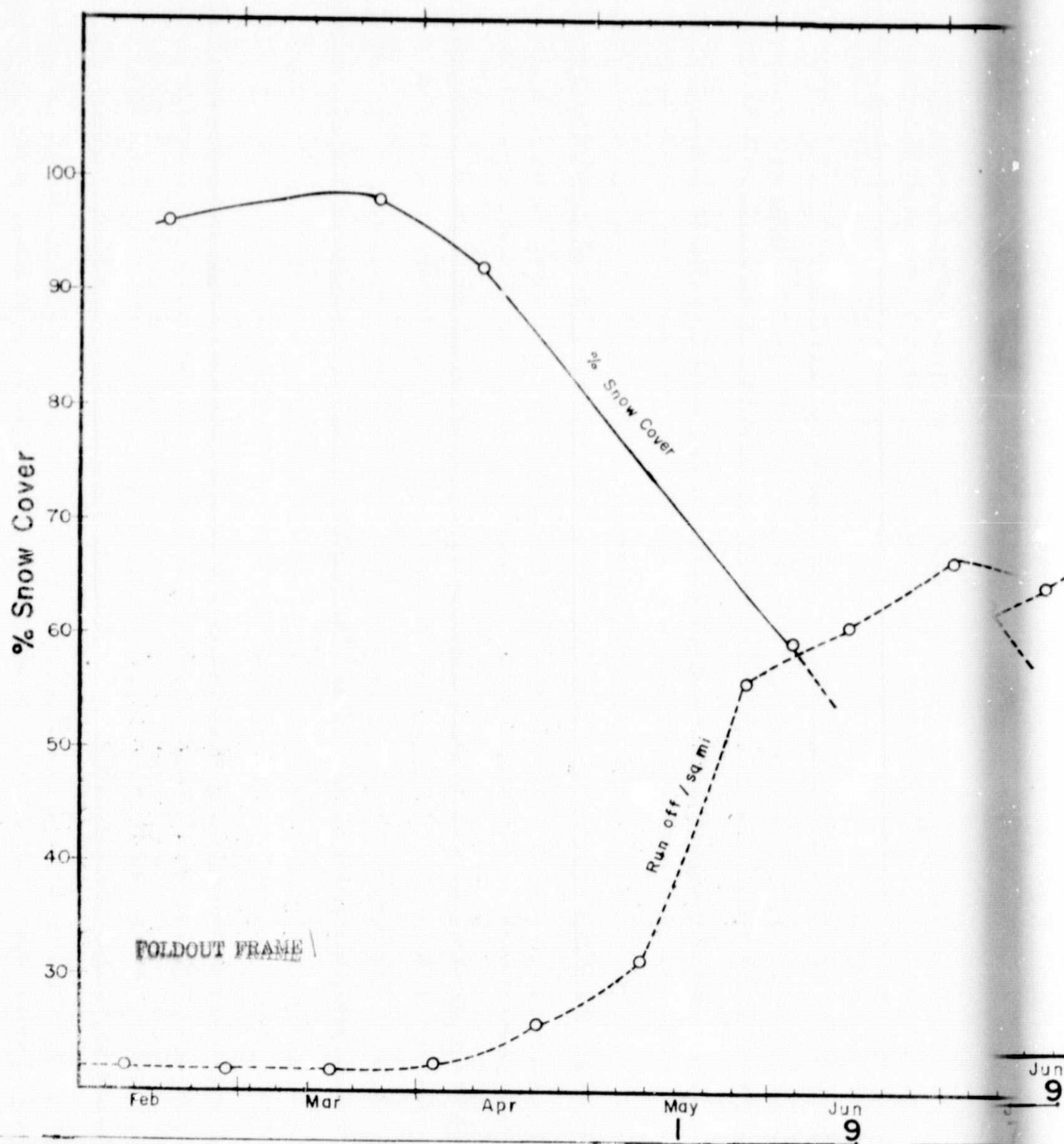
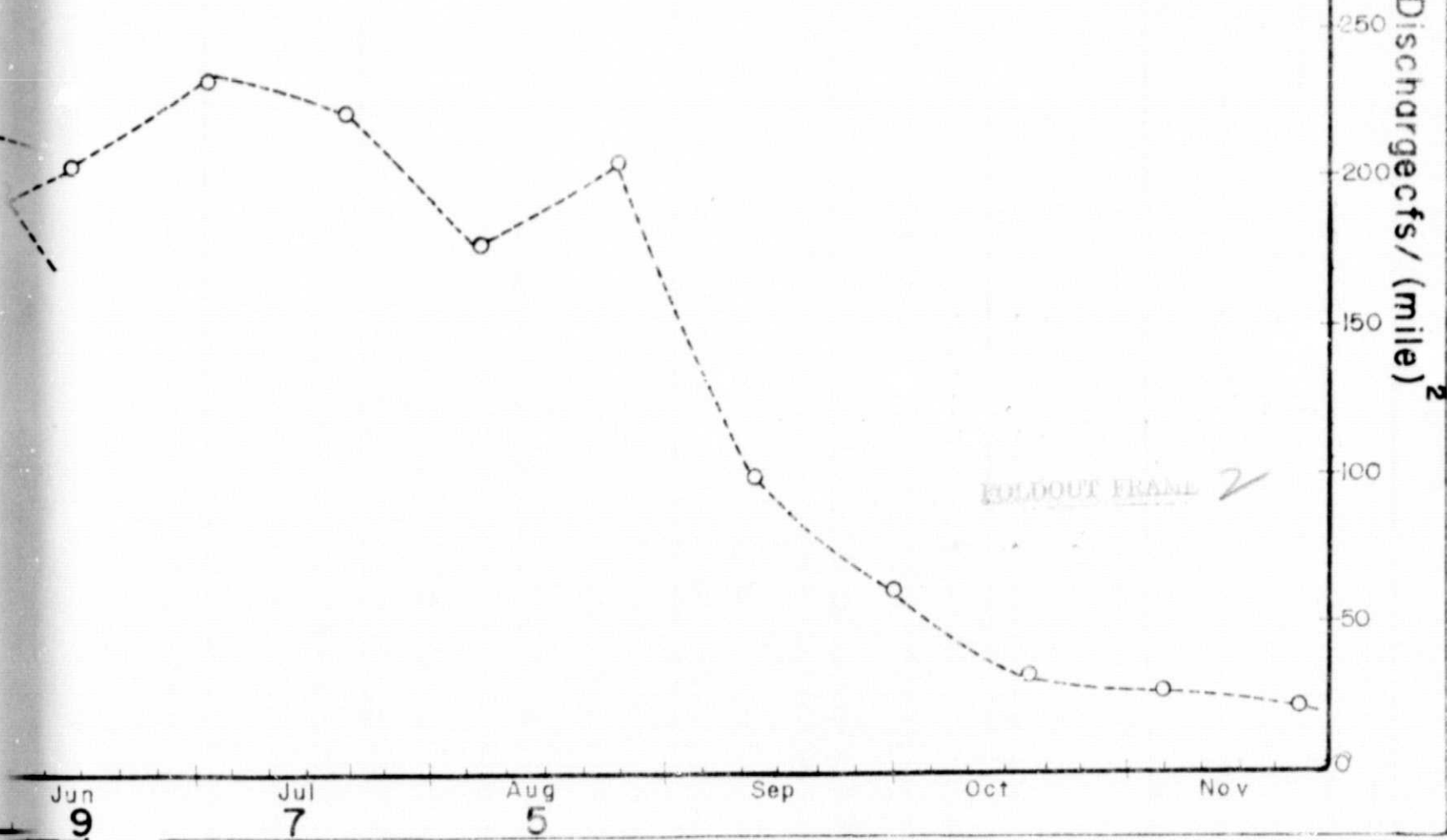


Fig- 10

SWAT RIVER NEAR KALAM 1975.

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18 Day Total Discharges/ (mile)²



FOLDOUT FRAME 2

% Snow Cover

100

90

70

60

50

40

30

FOLDOUT FRAME

Feb

Mar

Apr

May

Jun

Jun

% Snow Cover

Run off /sq mi

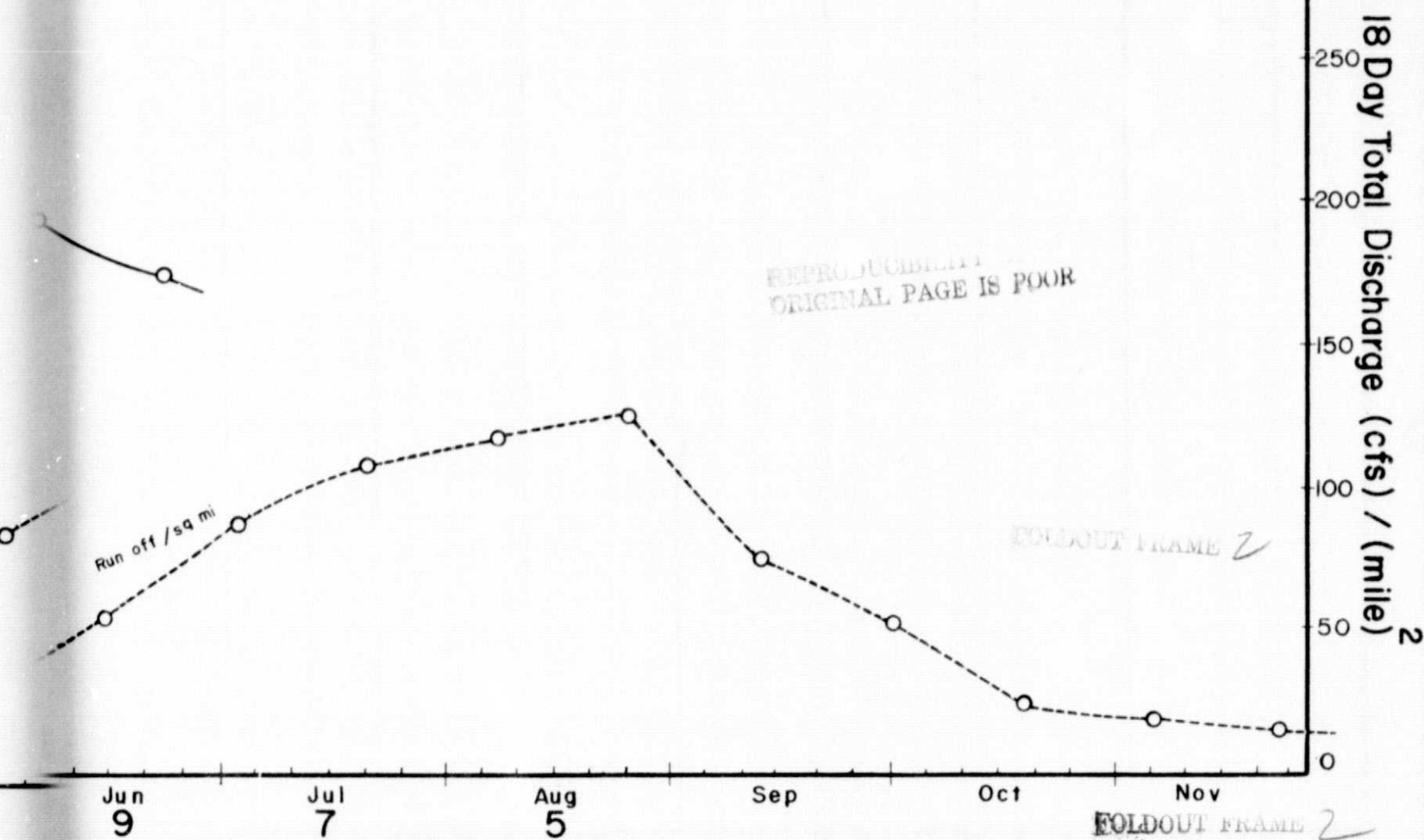
Run of

FOLDOUT FRAME

23

Fig-II

CHITRAL RIVER AT CHITRAL 1975.



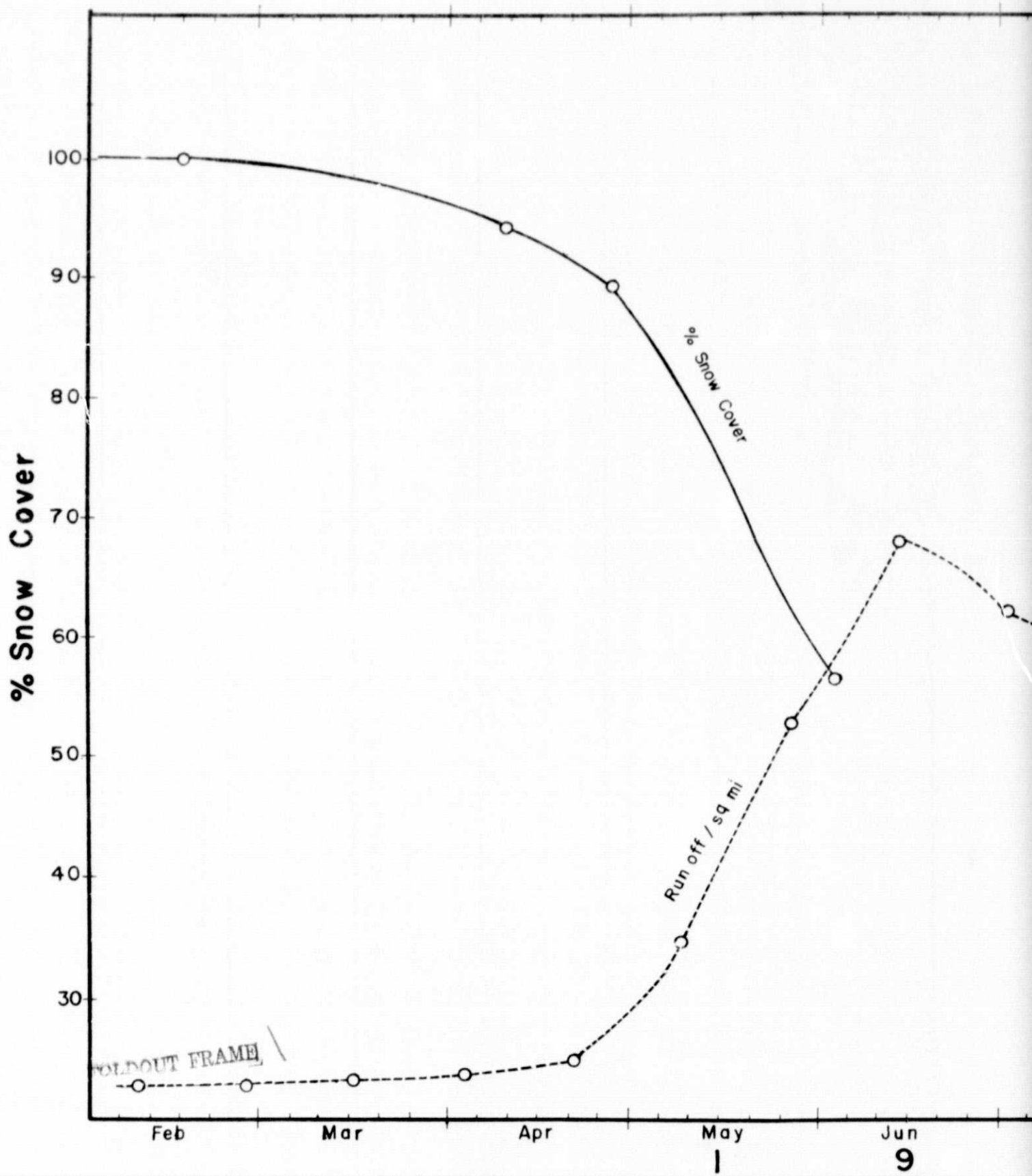
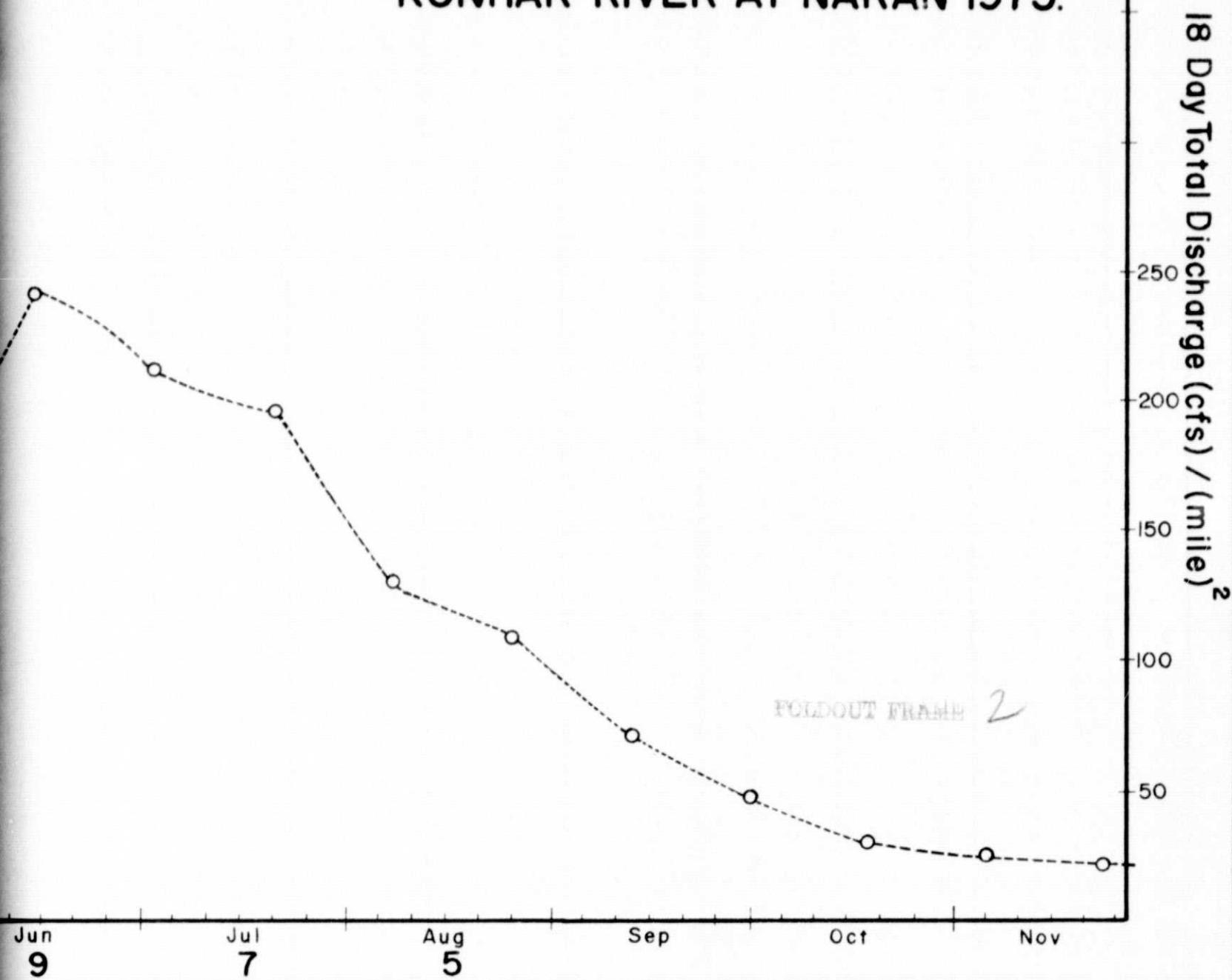


Fig-12

KUNHAR RIVER AT NARAN 1975.



FOLDOUT FRAME

2

FOLDOUT FRAME

24a

FOLDOUT FRAME

2

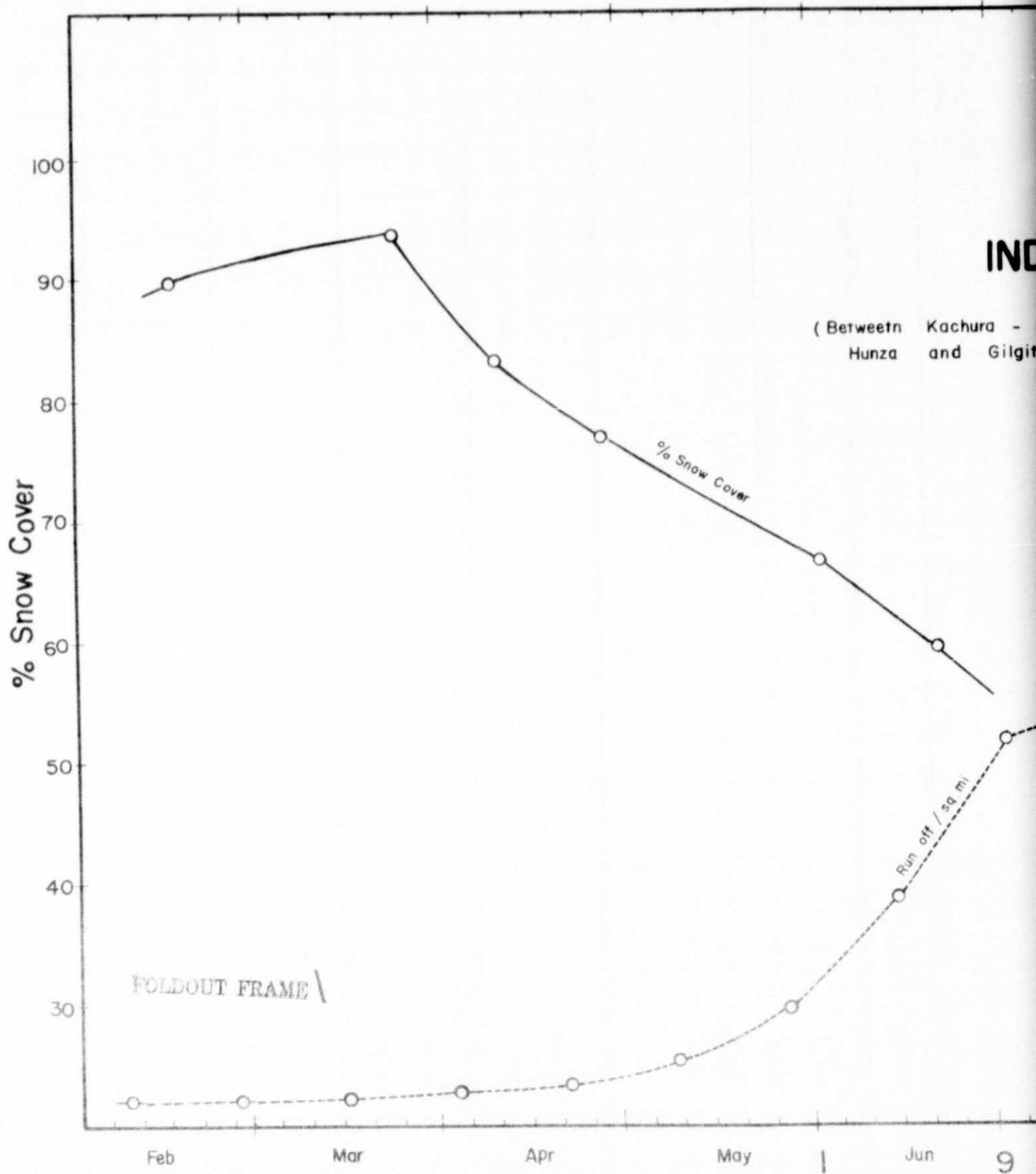
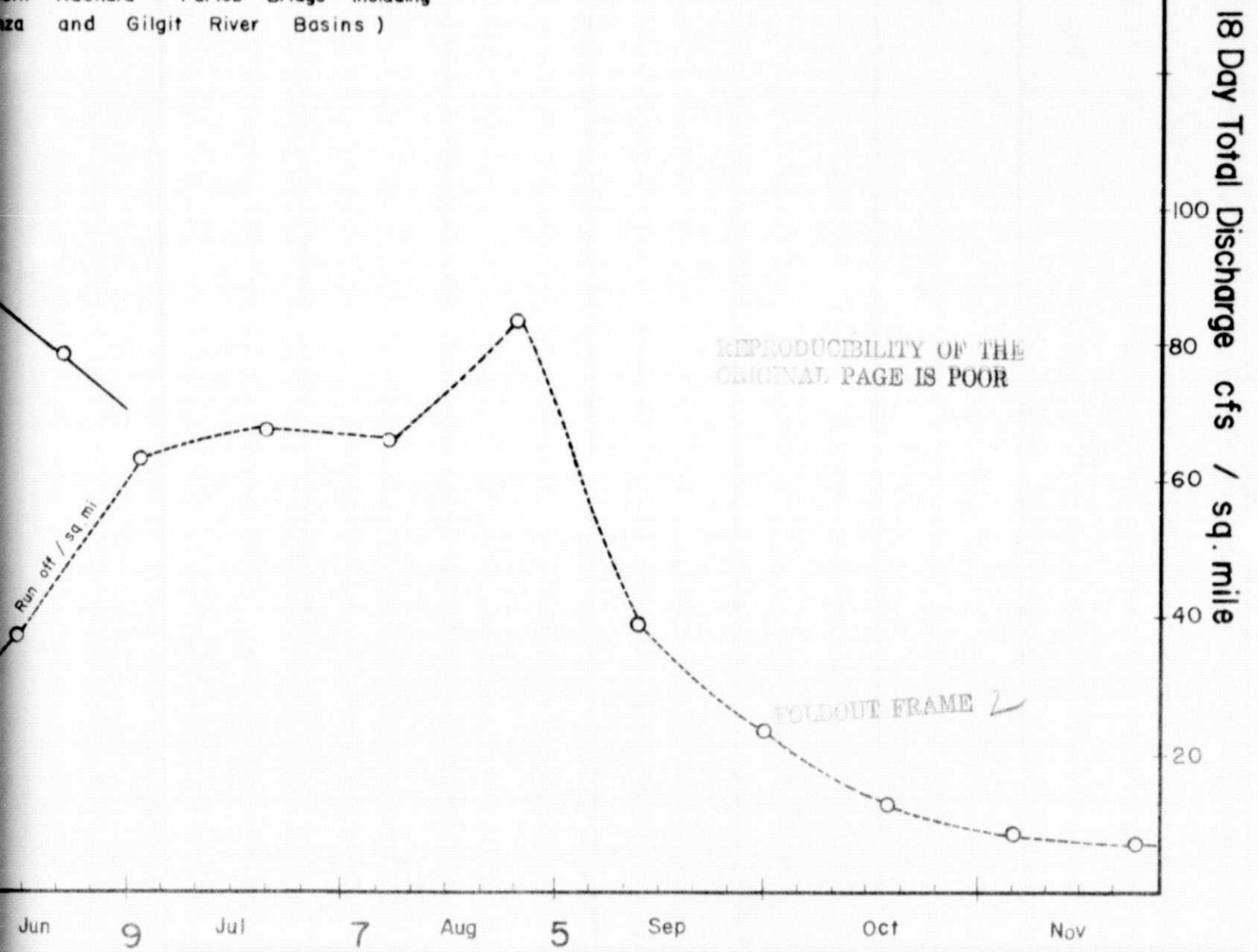


Fig-13

INDUS RIVER AT BESHAM QILA 1975.

atn Kachura - Partab Bridge Including
za and Gilgit River Basins)



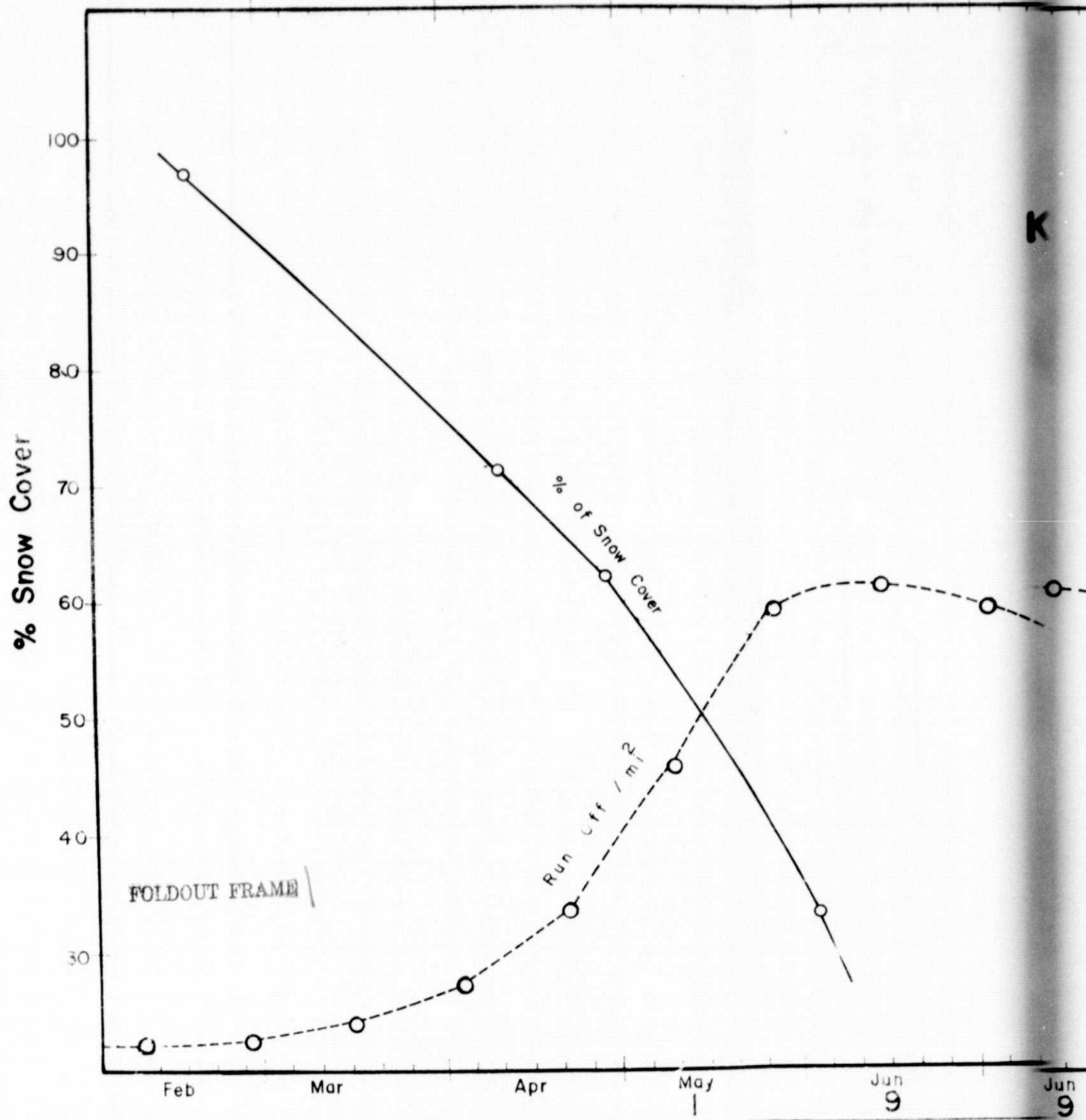
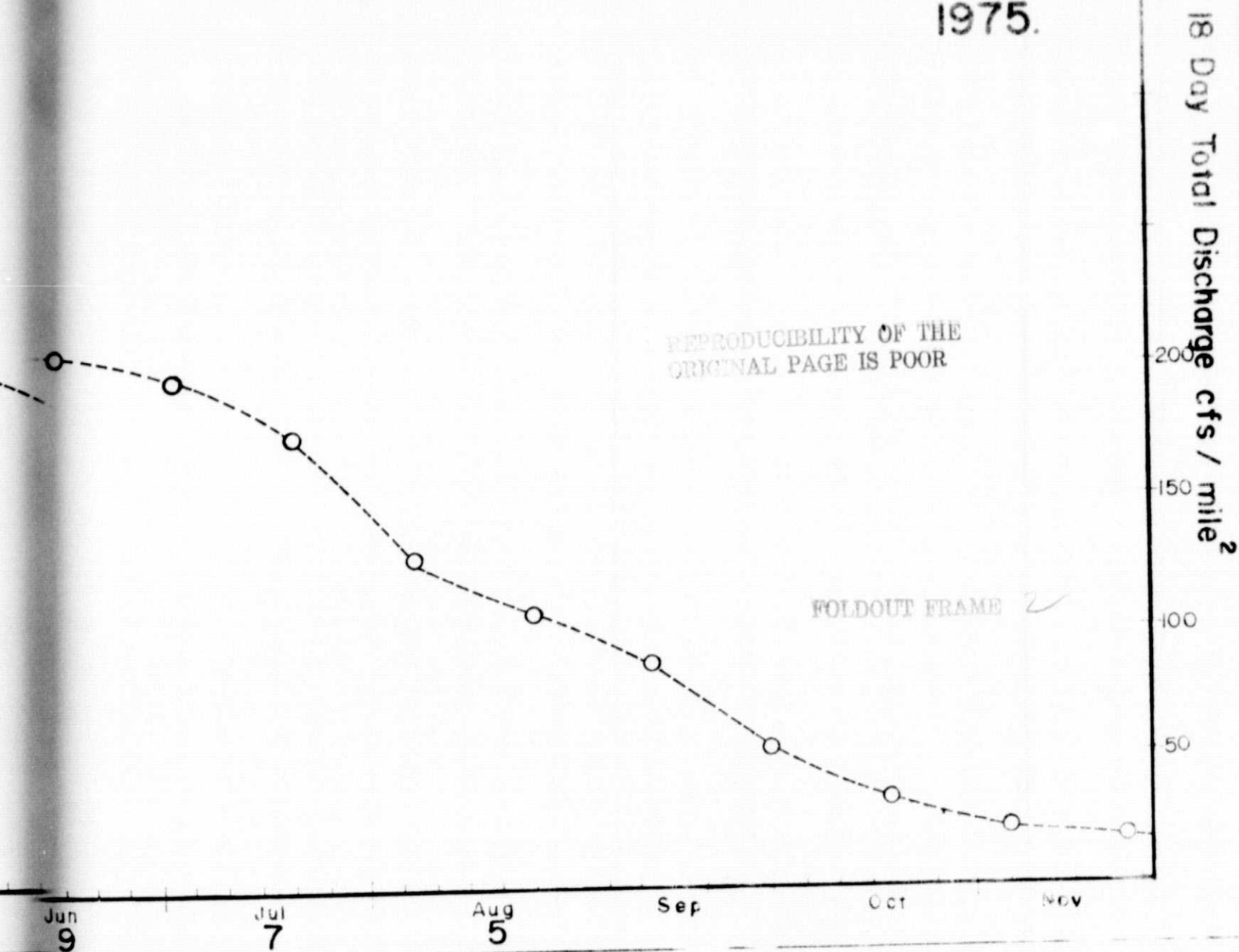
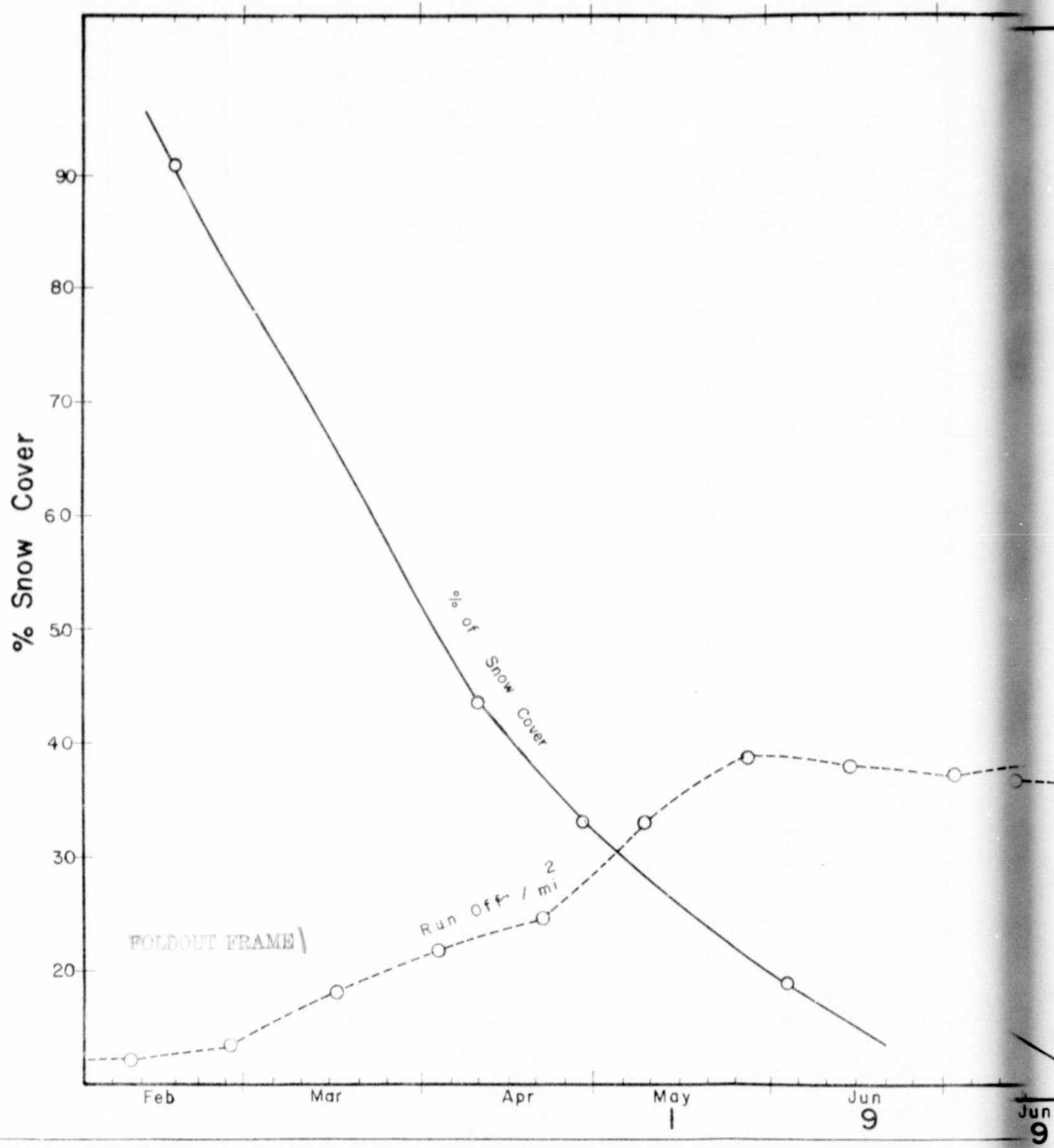


Fig- 14

K KISHANGANGA RIVER AT MUZAFFARABAD 1975.



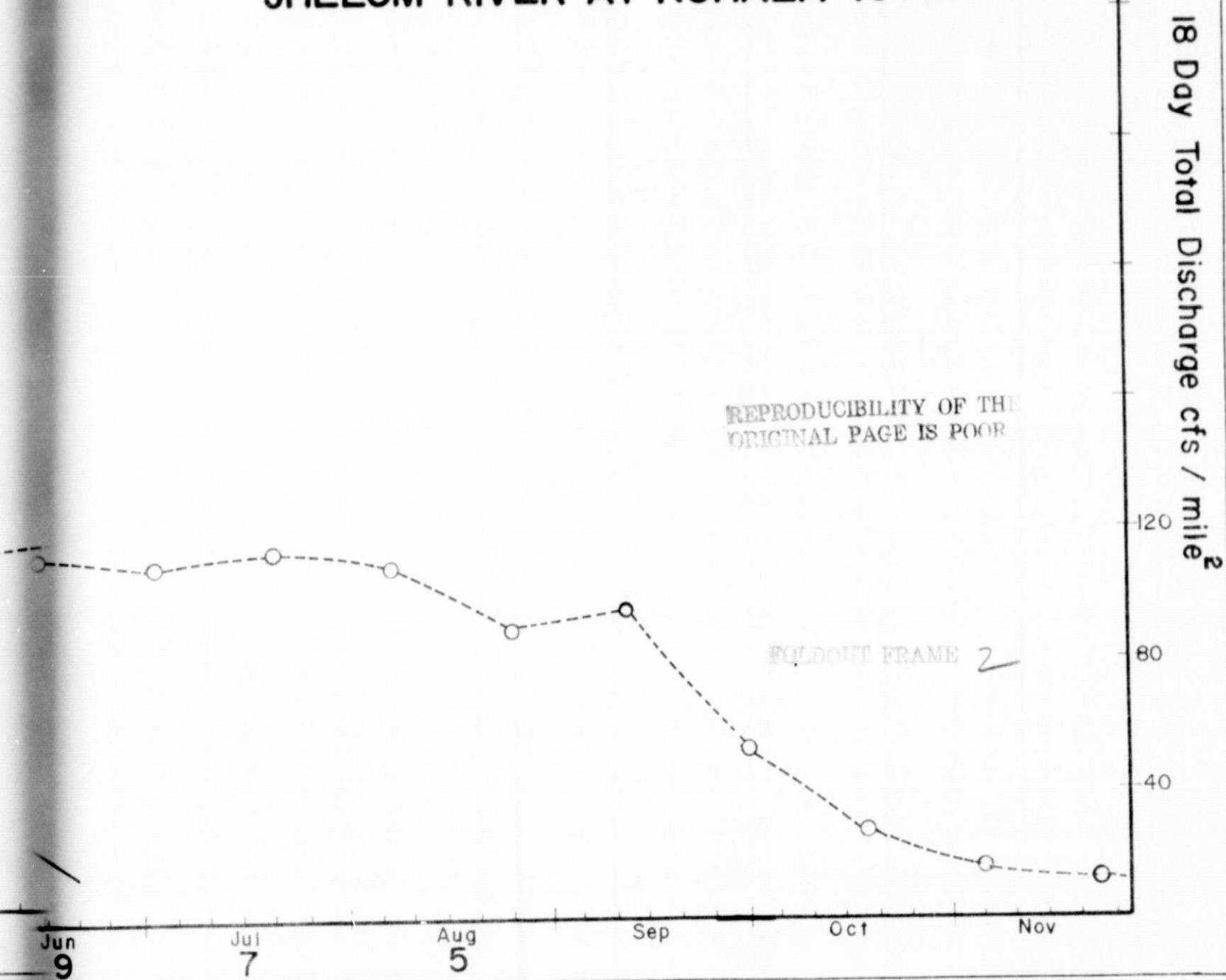


FOLDOUT FRAME

FOLDOUT FRAME

Fig- 15

JHELUM RIVER AT KOHALA 1975.



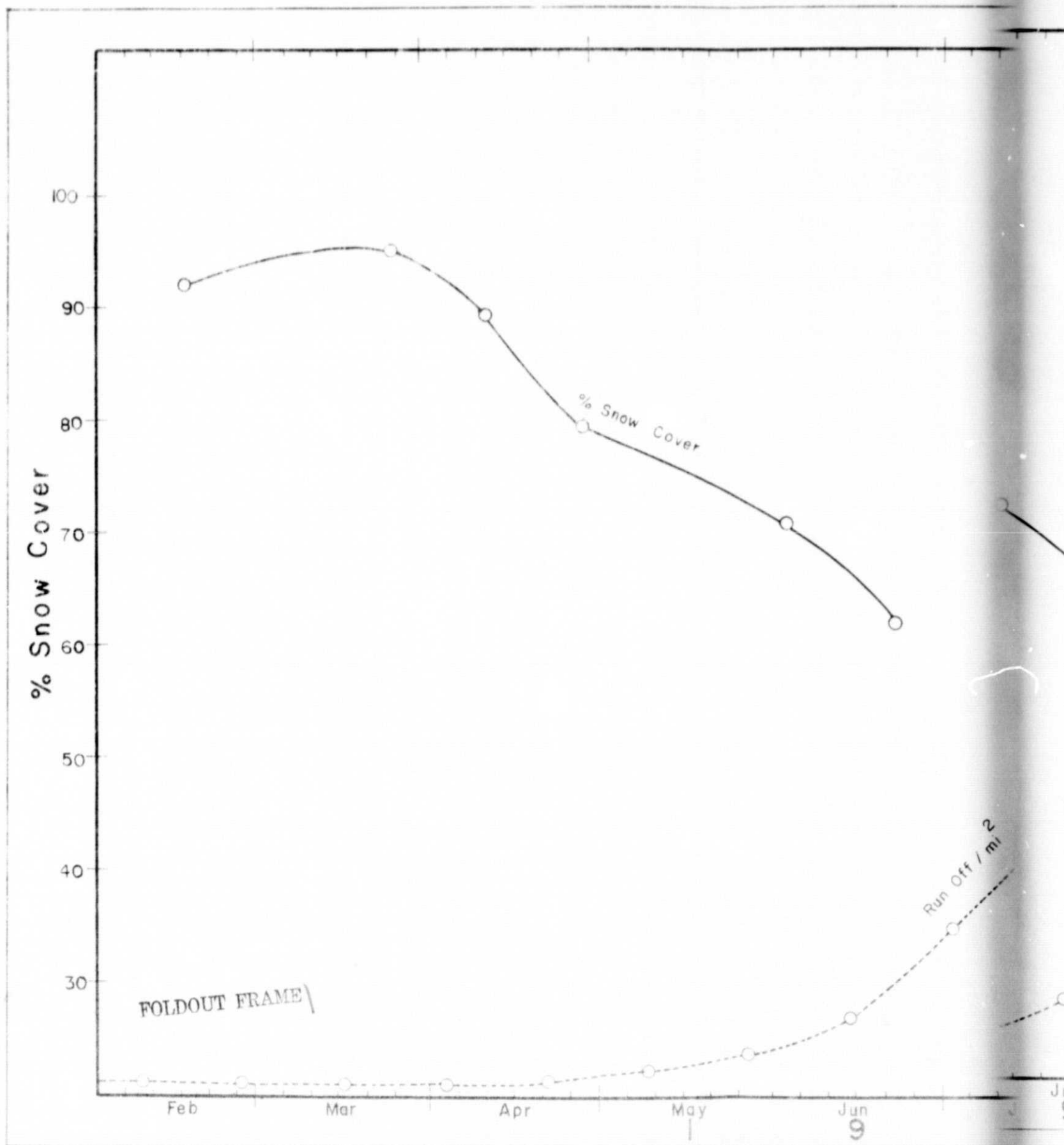
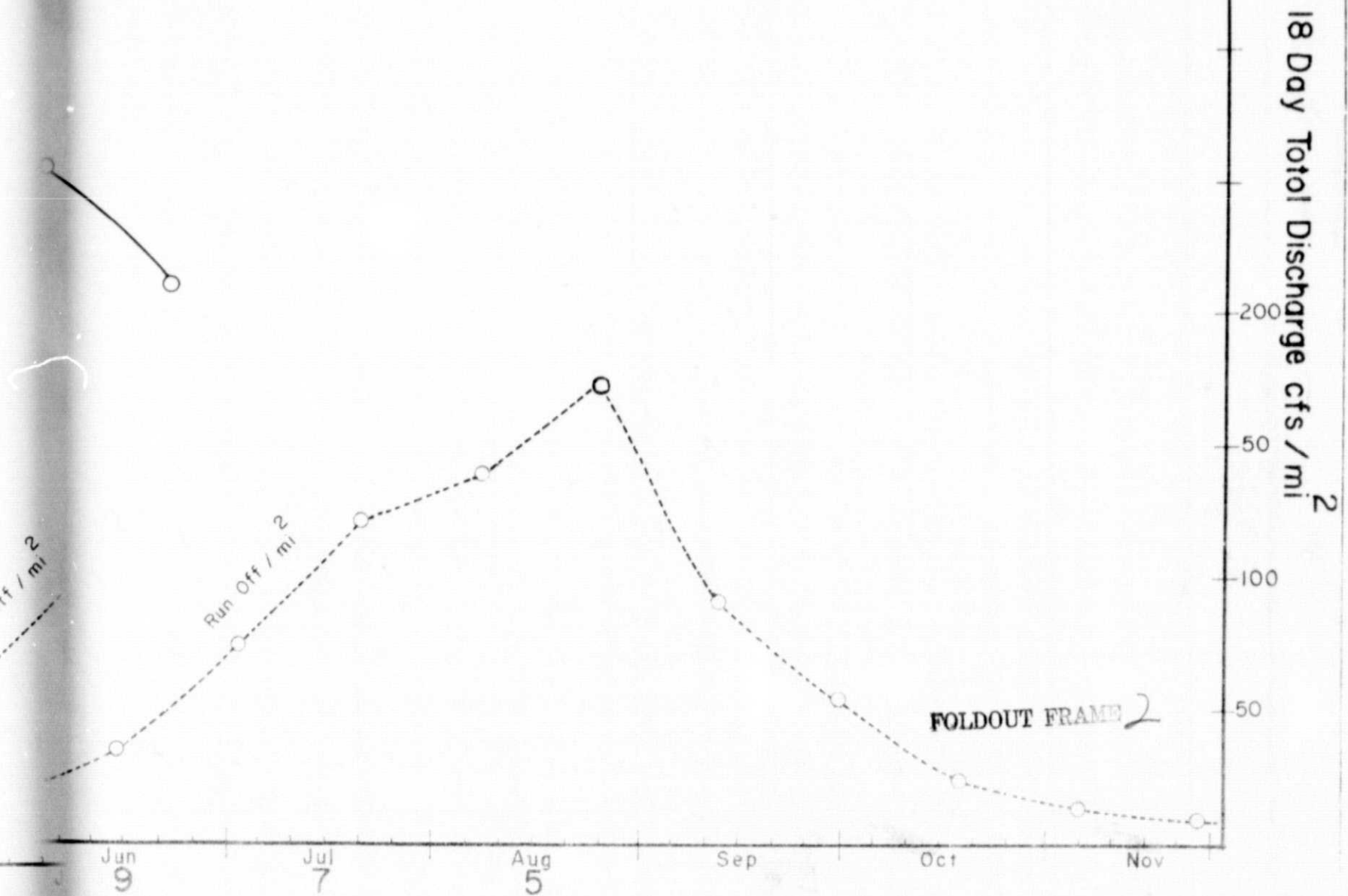


Fig- 16

HUNZA RIVER AT DAINYOR BR. 1975



FOLDOUT FRAME 2

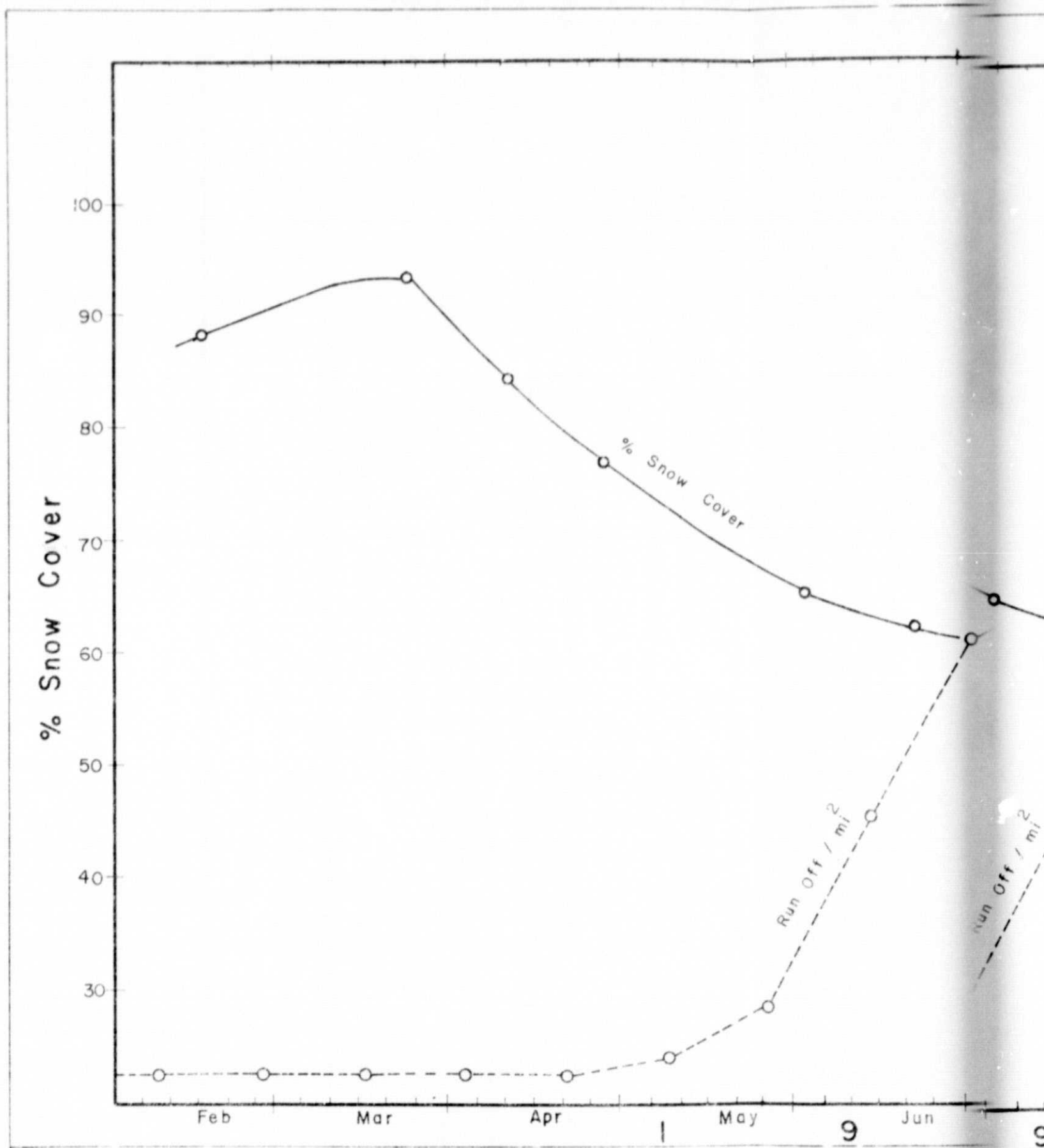
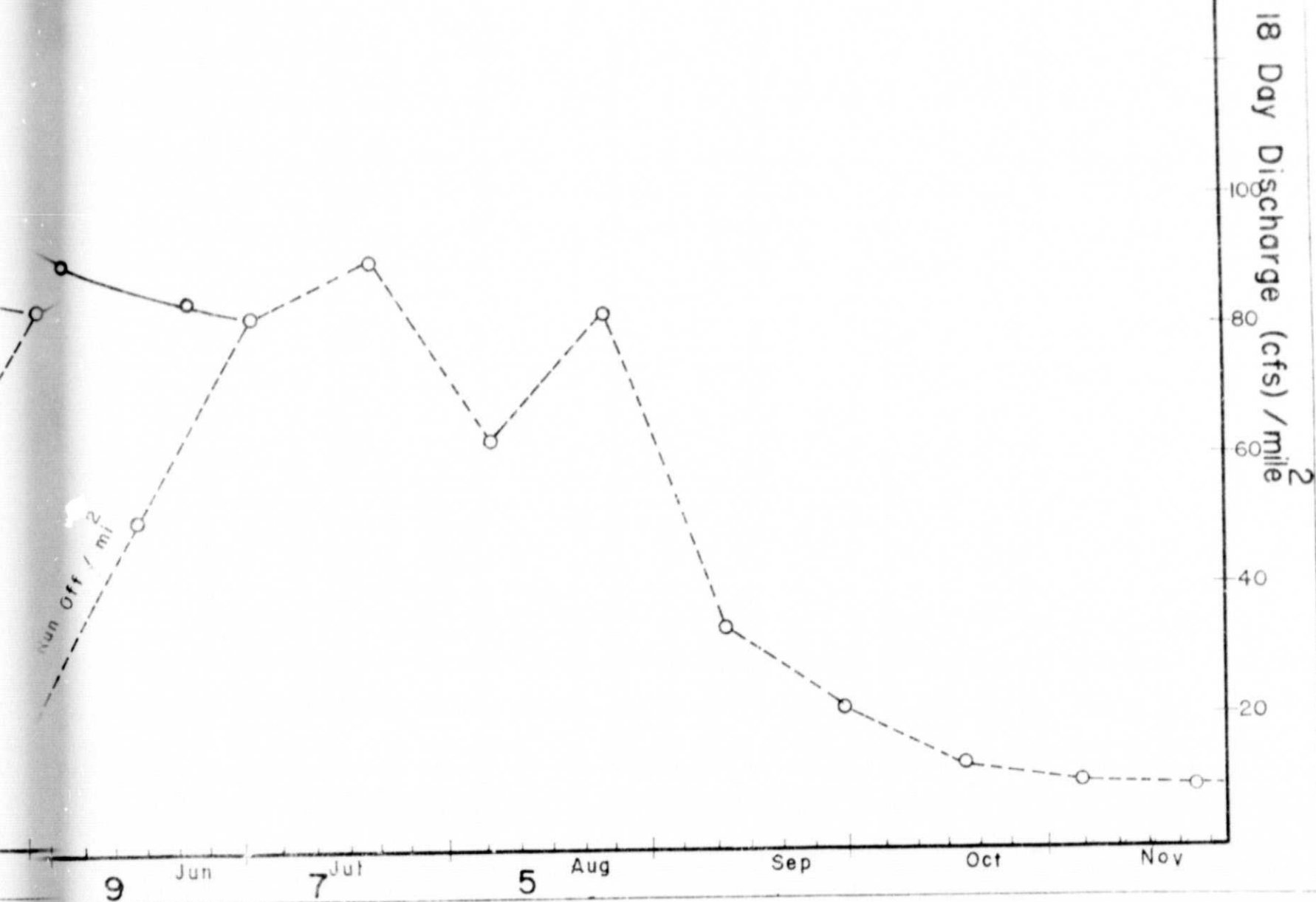


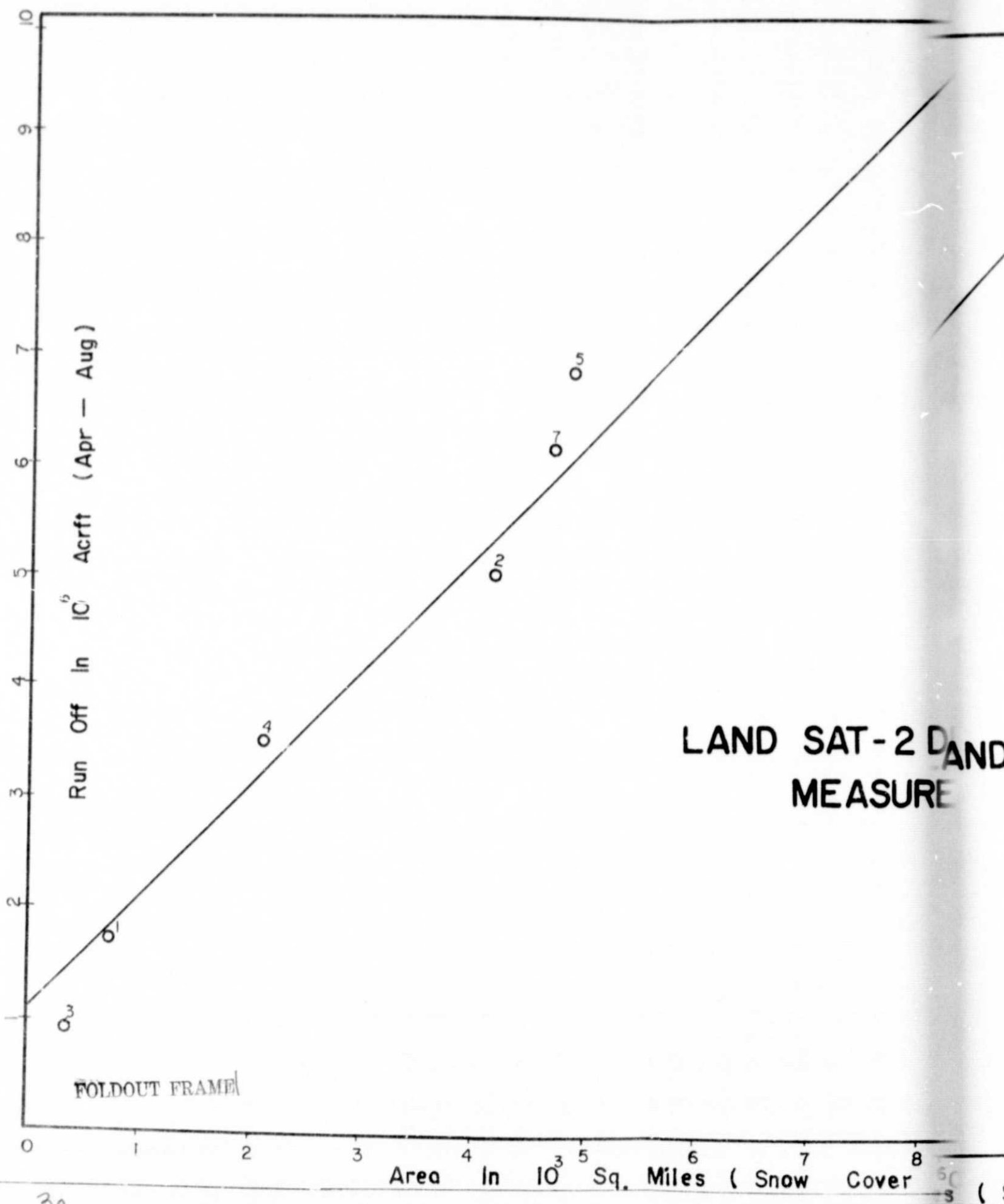
Fig- 17

GILGIT RIVER AT GILGIT 1975.



29a

FOLDOUT FRAME 2




$$R = 1.11 + 1.02 A$$

$$r^2 = 0.976$$

R - Apr - Aug Snow Melt Run Off
In MAF.

A - Area Under Snow On 1st Of April
In 1000 Sq Miles.

List Of Stations

1. Swat River Nr Kalam
2. Chitral R. At Chitral
3. Kunhar R. At Naran
4. Kishanganga R. At Muzaffarabad
5. Jhelum R. At Kohala
6. Gilgit R. At Alam Bridge
7. Hunza River At Dainyor Bridge

2 D AND SAT-2 DERIVED SNOW COVER ESTIMATES
RE MEASURED RUN OFF - 1975.

FOLDOUT FRAME 2

6 7 8 9 10
s (Snow Cover On First Of April)